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INSIDE THE JAVA VIRTUAL MACHINE

Memory Management and Troubleshooting

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Who am I?

- fhanik@apache.org
- Tomcat Committer / ASF member
- Co-designed the Comet implementation
- Implemented NIO connector in 6
- Responsible for session replication and clustering
- Been involved with ASF since 2001
- Member, Covalent Technical Team

What are we Talking About?

- Internals of Java Memory
- Spoken from a Java developer’s standpoint
- For other Java developers and system administrators

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Agenda

- Understanding the Java Memory Layout
- Out Of Memory Errors
  - Causes
  - Solution
- Garbage Collection Basics
- Java Tuning Options – Time Constraint
- Questions and Answers

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Storing Data in Memory

- Java runs as a single process
  - Does not share memory with other processes
- Each process allocates memory
  - We call this process heap
- Ways to allocate memory in a process
  - C (malloc and free)
  - C++ (new and delete)
  - Java (new and dereference -> Garbage Collection)

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Storing Data in Memory

- JVM manages the process heap
  - In most cases
  - JNI managed memory would be an exception, and there are others
- No shared memory between processes
  - At least not available through the Java API
- JVM creates a Java Heap
  - Part of the process heap
  - Configured through –Xmx and –Xms settings

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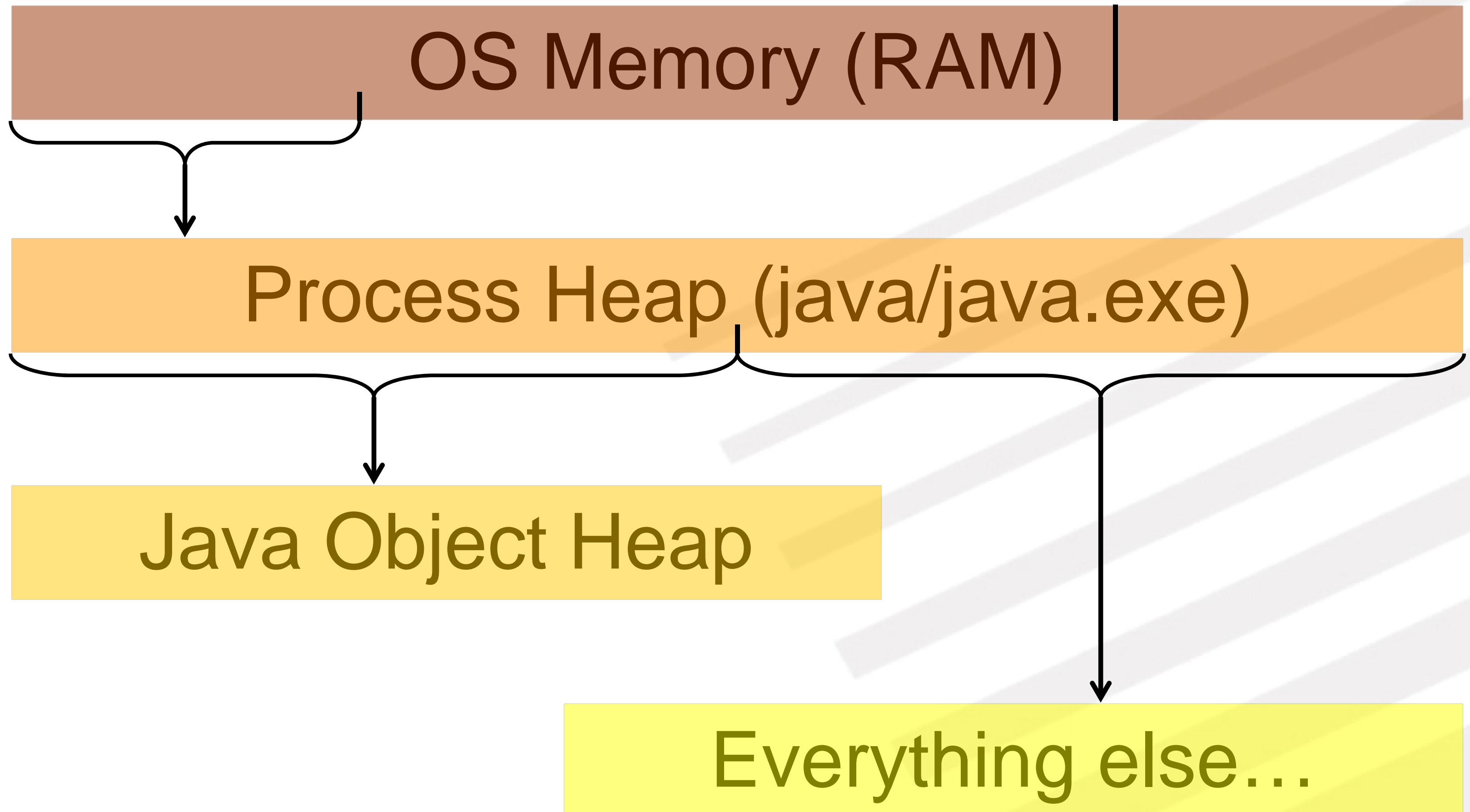
The JVM Process Heap



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JVM Process Heap

- Maximum size is limited
  - 32 bit size, roughly 2GB
  - 64 bit, much much larger ☺
- If 2GB is the max for the process
  - -Xmx1800m –Xms1800m – not very good
  - Leaves no room for anything else

Java Object Heap

- Also referred to as Java Heap
  - Often confused with JVM process heap
- Stores Java Objects
  - instances of classes
  - and the data the objects contain
    - Primitives
    - References

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Benefits of the Java Heap

- Pre-allocate large blocks of memory
- Allocation of small amounts of memory is very fast
- No need to fish for a free memory segment in RAM
- No fragmentation
- Continuous memory blocks can make a big difference
- NullPointerException vs. General Access Fault
  - NPE runtime error
  - GAF crash the process

Gotcha #1

- -Xmx, -Xms and –Xmn
  - Only controls the Java Object Heap
  - Often misunderstood to control the process heap
- Confusion leads to incorrect tuning
  - And in some cases, the situation worsens

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Java Object Heap

- So how is the Java Heap allocated?
- -XX:MinHeapFreeRatio=
  - Default is 40 (40%)
  - When the JVM allocates memory, it allocates enough to get 40% free
  - Huge chunks, very large default
  - Not important when –Xms == -Xmx
- -XX:MaxHeapFreeRatio=
  - Default 70%
  - To avoid over allocation
  - To give back memory not used
- As you can see, to provide performance and avoid fragmentation, excessively large blocks are allocated each time

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Java Object Heap

- Object allocation statistics
  - 80-98% of newly allocated are extremely short lived (few million instructions)
  - 80-98% die before another megabyte has been allocated
  - Typical programs
- Tomcat Core (no webapps)
  - Lots of long lived objects
  - Still a small memory footprint

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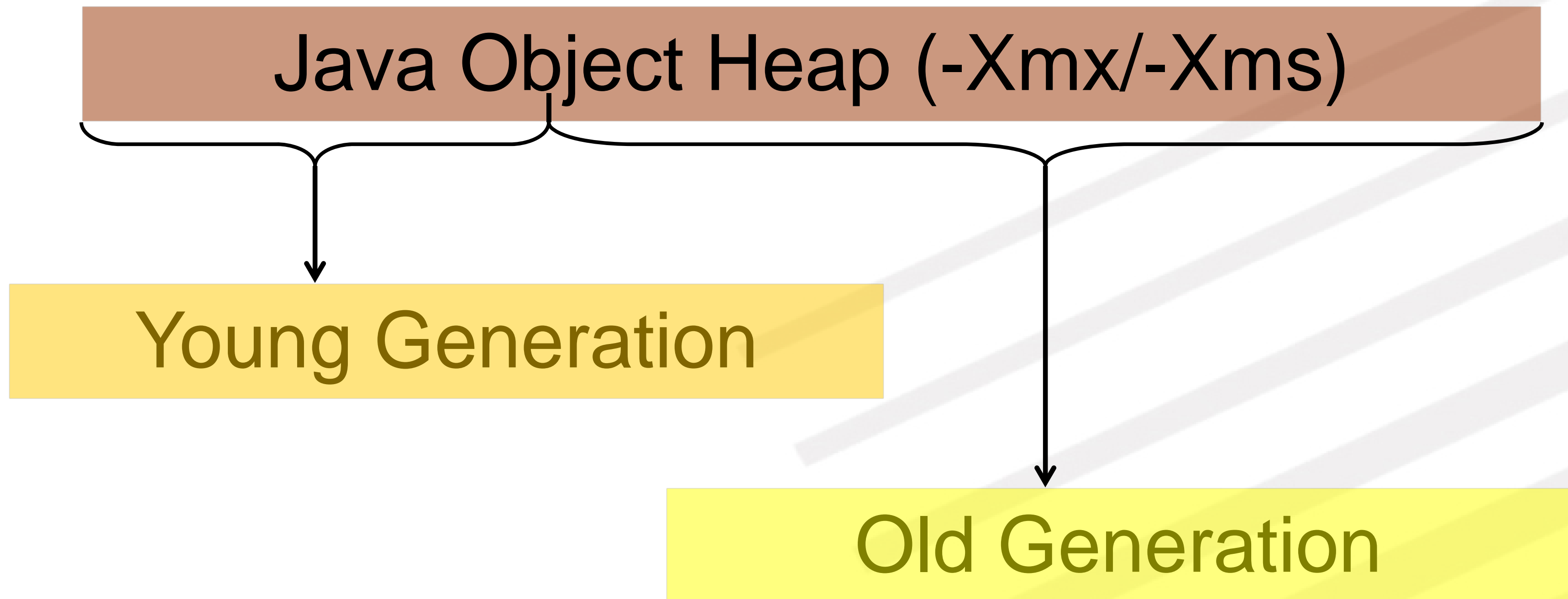
Java Object Heap



A good size for the YG is 33% of the total heap

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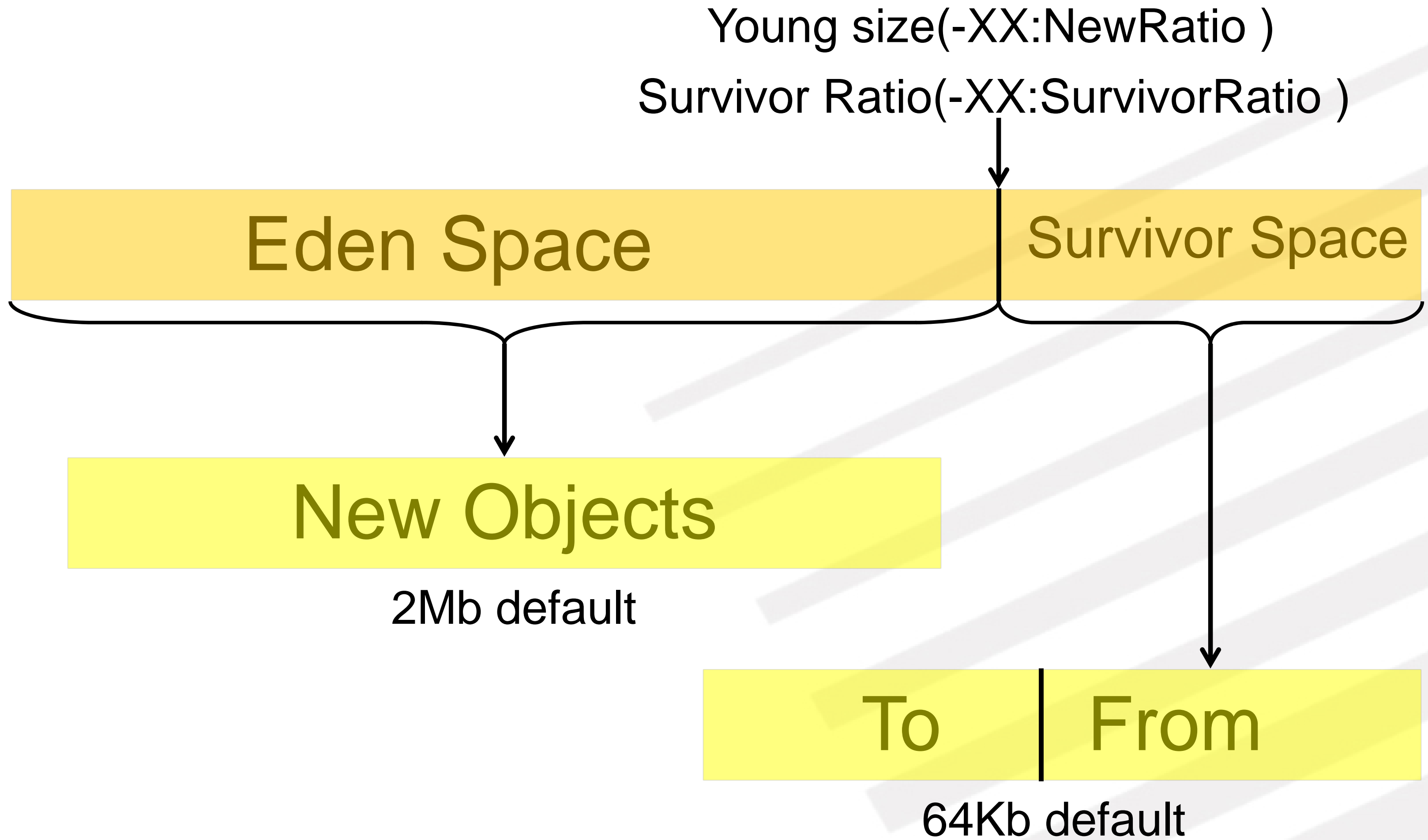
Java Object Heap

- Young Generation
  - All new objects are created here
  - Only moved to Old Gen if they survive one or more minor GC
  - Sized Using
    - -Xmn – not preferred (fixed value)
    - -XX:NewRatio=<value> - preferred (dynamic)
- Survivor Spaces
  - 2, used during the GC algorithm (minor collections)

Young Generation



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Gotcha #2

- Problem
  - Multithreaded apps create new objects at the same time
  - New objects are always created in the the EDEN space
  - During object creation, memory is locked
  - On a multi CPU machine (threads run concurrently) there can be contention

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Gotcha #2

- Solution
  - Allow each thread to have a private piece of the EDEN space
- Thread Local Allocation Buffer
  - -XX:+UseTLAB
  - -XX:TLABSize=<size in kb>
  - -XX:+ResizeTLAB
  - (On by default on multi CPU machines and newer JDK)
- Analyse TLAB usage
  - -XX:+PrintTLAB
- JDK 1.5 and higher (GC ergonomics)
  - Dynamic sizing algorithm, tuned to each thread

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Old Generation

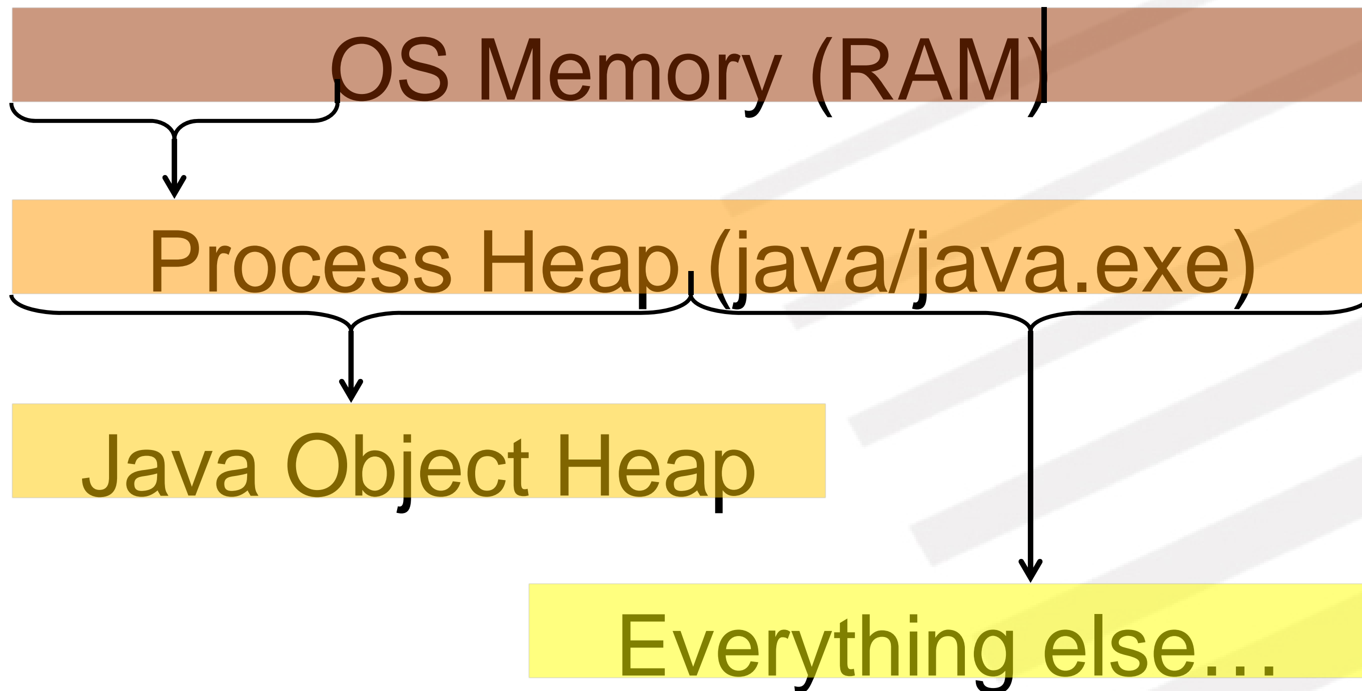
Tenured Space

5Mb min 44Mb max (default)

Garbage collection presentation will explain in detail how these spaces are used during the GC process.

JVM Process Heap

- Java Object Heap
  - A handful, but a small part of the story



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JVM Process Heap

Everything else…

- Permanent Space
- Code Generation
- Socket Buffers
- Thread Stacks
- Direct Memory Space
- JNI Code
- Garbage Collection
- JNI Allocated Memory

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Permanent Space

- Permanent Generation
  - Permanent Space (name for it)
  - 4Mb initial, 64Mb max
  - Stores classes, methods and other meta data
  - -XX:PermSize=<value> (initial)
  - -XX:MaxPermSize=<value> (max)
- Common OOM for webapp reloads
- Separate space for pre-historic reasons
  - Early days of Java, class GC was not common, reduces size of the Java Heap

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Gotcha #3

- Permanent Space Memory Errors
  - Too many classes loaded
  - Classes are not being GC:ed
  - Unaffected by –Xmx flag
- Identified by
  - java.lang.OutOfMemoryError: PermGen space
- Many situations, increasing max perm size will help
  - i.e., no leak, but just not enough memory
  - Others will require to fix the leak

JVM Process Heap

Everything else…

- Permanent Space
- Code Generation
- Socket Buffers
- Thread Stacks
- Direct Memory Space
- JNI Code
- Garbage Collection
- JNI Allocated Memory

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Code Generation

- Converting byte code into native code
- Very rare to cause memory problems
- JVM will most likely crash if it doesn't have enough mem for this operation
  - Never seen it though

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JVM Process Heap
Everything else…

- Permanent Space
- Code Generation
- Socket Buffers
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TCP connections

- Each connection contains two buffers
  - Receive buffer ~37k
  - Send buffer ~25k
- Configured in Java code
  - So might not be exposed through applications configuration
- Usually hit other limits than memory before an error happen
  - IOException: Too many open files (for example)

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JVM Process Heap
Everything else…

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Thread Stacks

- Each thread has a separate memory space called “thread stack”
- Configured by –Xss
- Default value depends on OS/JVM
- As number of threads increase, memory usage increases

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Gotcha #4

- java.lang.OutOfMemoryError:
  unable to create new native thread
- Solution
  - Decrease –Xmx and/or
  - Decrease –Xss
  - Or, you have a thread leak, fix the program
- Gotcha
  - Increasing –Xmx (32bit systems) will leave less room for threads if it is being used, hence the opposite of the solution
  - Too low –Xss value can cause java.lang.StackOverflowError

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JVM Process Heap

Everything else…

- Permanent Space
- Code Generation
- Socket Buffers
- Thread stacks
- Direct Memory Space
- JNI Code
- Garbage Collection
- JNI Allocated Memory

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Direct Memory Space

- Ability to let Java developers map memory outside the Java Object Heap
- java.nio.ByteBuffer.allocateDirect
- java.lang.OutOfMemoryError:
  Direct buffer memory
- Adjusted by
  - -XX:MaxDirectMemorySize=<value>

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JVM Process Heap

Everything else…

- Permanent Space
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- Socket Buffers
- Thread stacks
- Direct Memory Space
- JNI Code
- Garbage Collection
- JNI Allocated Memory

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JNI

- Code needs memory
  - Usually very little
- JNI programs also allocate memory
  - Error allocating memory.[NativeMemory.c] (my code)
  - JVM goes berserk or crashes or if the JNI code can handle it gracefully, you’re lucky
- Linux way of dealing with mem leak
  - Kill the process!

JVM Process Heap
Everything else…

- Permanent Space
- Code Generation
- Socket Buffers
- Thread stacks
- Direct Memory Space
- JNI Code
- Garbage Collection
- JNI allocated memory

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Garbage Collection

- Also uses memory
  - Threads
  - Memory to store GC info
- If there isn't enough memory for GC, then the system will not be functioning at all

GC History

- First time around 1959 – LISP language
- The idea
  - automatic memory cleanup
  - Easier to write code
  - Easier to debug
- What it does
  - Maps memory in memory
  - The Java Object Heap is such a map

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Phases of GC

- Lock it down
  - All objects that are to take part in the GC must be locked, so that they don't mutate
- Mark
  - Iterate through all objects
  - Mark the "unreachable" as garbage
- Sweep
  - Remove all previously marked objects
  - Reclaim memory

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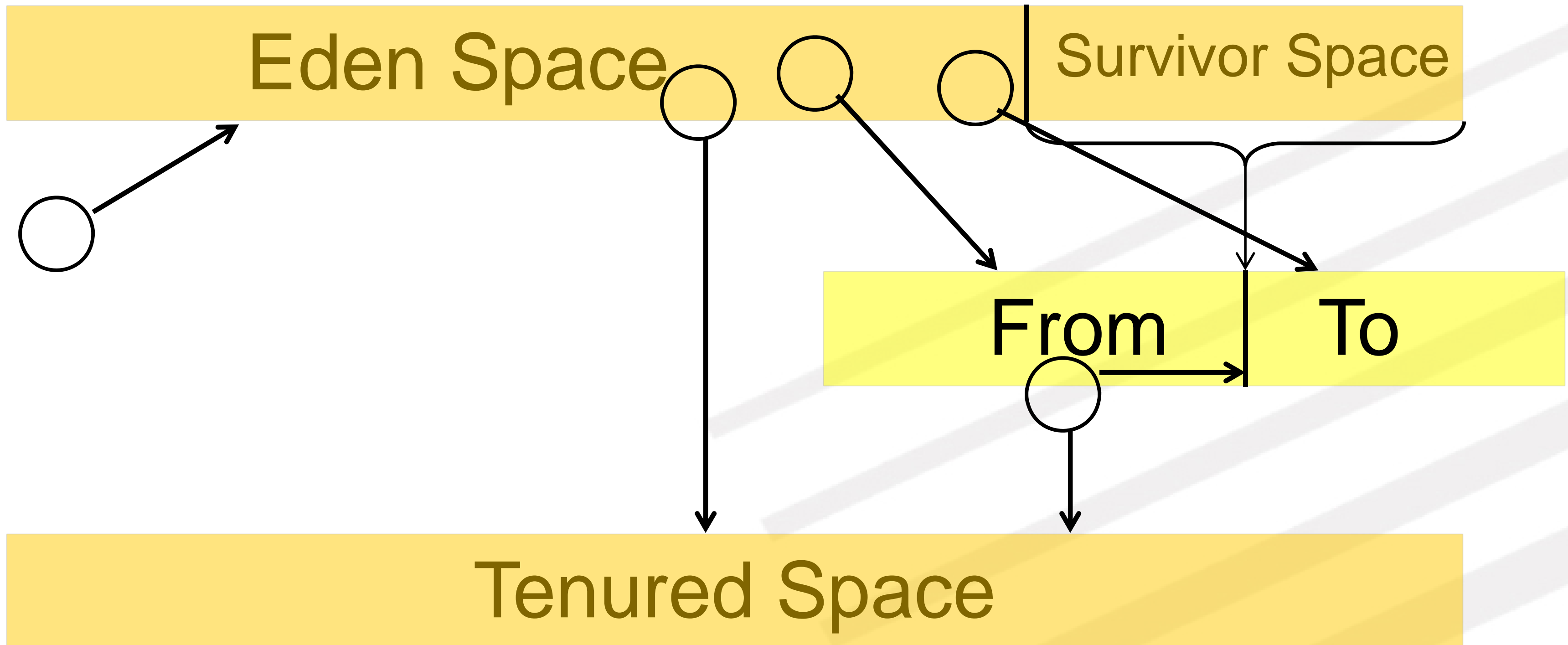
Early Version of Java

- Garbage Collector wasn't very well tuned
- Only one algorithm was available
- Mark and Sweep entire heap
  - Takes a very long time
  - Time spent is dependent on the size of the heap
  - That is why the "Permanent Space" was invented
    - And cause un/reloading of classes wasn't very common either
- Also known as "stop-the-world" gc
  - The entire JVM is locked down

Strategies

- Stop The World
- Incremental
  - Time GC with new object creation
  - If GC runs, suspend new allocation
- Concurrent/Parallel
  - Allocation happens at the same time as GC
  - Very complex locking regimes
  - Generations/Spaces make it easier
- CMS stands for
  - Concurrent
  - Mark
  - Sweep

How It Works



... collection

Copy from Eden to 2nd ... objects remain in Eden or 1st

Copy from 1st to 2nd

These get copied to the tenured

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How it Works

- One survivor space is always empty
  - Serves as destination for minor collections
- Objects get copied to the tenured space when the 2nd survivor space fills up
- Major collections occur when the tenured space fills up
  - Major collections free up Eden and both survivor spaces

New and Fancy

- Concurrent/Parallel Garbage Collection
- -XX:+UseParNewGC
  - Parallel GC in the New(Young) Generation
- -XX:+UseConcMarkSweepGC
  - Concurrent in the Old generation
- Use these two combined
  - Multi CPU box can take advantage of this

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Sun Recommended

- GC Settings
  - -XX:+UseConcMarkSweepGC
  - -XX:+CMSIncrementalMode
  - -XX:+CMSIncrementalPacing
  - -XX:CMSIncrementalDutyCycleMin=0
  - -XX:+CMSIncrementalDutyCycle=10
  - -XX:+UseParNewGC
  - -XX:+CMSPermGenSweepingEnabled
- To analyze what is going on
  - -XX:+PrintGCDetails
  - -XX:+PrintGCTimeStamps
  - -XX:-TraceClassUnloading

Minor Notes

- -XX:+UseParallelGC <> -XX:+UseParNewGC
- -XX:ParallelGCThreads=<nr of cpu>
  - Use with ParallelGC setting
- If you have 4 cpus and 1 JVM
  - Set value to 4
- If you have 4 cpus and 2 JVM
  - Set value to 2
- If you have 4 cpus and 6 JVM
  - Set value to 2

GC Ergonomics

- Started with JDK 1.5
- JVM is self trained and GC strategy adapts
- Rules/Guidelines can be set using command line options
  - Max pause time goal
    - The longest pause time to suspend application
  - Throughput goal
    - Time spent GC vs. time spent outside GC
- Not guaranteed

Out Of Memory Errors

- There is a seamless way to get info
  - -XX:+HeapDumpOnOutOfMemoryError
- No performance impact during runtime
- Dumping a –Xmx512m heap
  - Create a 512MB .hprof file
  - JVM is “dead” during dumping
  - Restarting JVM during this dump will cause unusable .hprof file

Gotcha's

- Major collections don't run until tenured is full
- What does that mean?
  - -Xmx1024m
  - Current heap could be 750MB
  - 500MB of "dead" objects
  - If VM is idle, could stay like that for a very long time
  - Wasting 500MB of RAM for an idle JVM

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Monitoring Agents

- Monitor memory usage
- If system is idle, force a GC
- Can be done automatically and with remote agents
- Example would be:
- www.yourkit.com
- And script the client to take telemetry readings from an embedded agent

Thank You

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